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Composited Local Area Forecast Techniques

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A previously developed advection forecast technique was modified to include data extracted from satellite imagery. A forecast experiment was then conducted using a data base gathered at AFGL during March 1984. This experiment was designed to test the usefulness of: (a) 3-hour forecast updates, (b) a biquadratic interpolation, and (c) cloud and precipitation information from satellite imagery. The test results confirmed earlier tests in that advection using space-averaged 500-mb winds produced the best overall scores and that in general the scores for 1 - 15 hours were better than persistence. The age of the advection flow (3,6 or 9 hours old) did not affect forecast score, making updates useful. The biquadratic interpolation procedure produced better fits to observation than bilinear and appears to have improved forecasts. There was but a small benefit from adding satellite information to surface observations when forecasting cloud cover and hourly precipitation. The difficulties of trying to forecast even 30 to 50 percent of the time-change variance suggest that alternative approaches such as mesoscale modeling will be needed for accurate, reliable short-range forecasts.

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1. INTRODUCTION

1.1 Overview

As part of an on-going effort to improve short-range local weather forecasts, a number of experiments have been conducted to test an "advection" forecast technique. The basis for this technique is the simple differential equation to forecast the local change in a weather parameter "Q":

$$\underset{\text{local change}}{\frac{\partial Q}{\partial t}} = \underset{\text{advective change}}{-\vec{V} \cdot \nabla Q} - \underset{\text{nonconservative term}}{\frac{dQ}{dt}} \tag{1}$$

where $\vec{V}$ is a three-dimensional wind vector. At levels above the boundary layer (above about 1.5 km or 5000 ft), the equations for wind, temperature, and humidity are relatively easy to solve in numerical models, as the nonconservative terms can either be expressed in terms of other variables, or, if believed to be small, can be ignored. In the boundary layer, the turbulent fluxes of heat, moisture and momentum are relatively large and variable, greatly complicating the forecast problem. To illustrate, the "surface" winds (3 m or 10 ft) have typical speeds of 2 - 5 m/s (5 -10 kt), yet winter weather patterns typically move at 10 -15 m/s (20 - 30 kt). If the patterns move systematically, the advective changes using the 2 - 5 m/s surface winds can account for only a small portion of the local changes of

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wind, temperature, humidity, and visibility, with most of the change being due to nonconservative processes.

Forecasters have long noted that many of the surface weather patterns tend to move with upper-level disturbances, whose motions are governed by winds aloft. Thus we can rewrite the forecast equation in the following form:

$$\frac{\partial Q}{\partial t} = -\vec{V}* \cdot \nabla Q \qquad (2)$$

where $\vec{V}*$ is a horizontal wind vector determined from upper level winds. We can consider this vector as driving the nonconservative terms through effects on divergence, vertical motion and wind shear.

1.2 Prior Studies

An early experiment using weather satellite data[1] found that a motion vector derived from successive satellite cloud images worked well in short-range forecasts, but the simple 700-mb wind was nearly as effective and usually easier to obtain. Later experiments[2] tested winds at 850, 700, and 500 mb, as well as vertically integrated winds. Fjortoft[3] developed a graphical procedure to create space-averaged wind flows (500-mb level) which were then used to determine geostrophic vorticity, and also to advect and predict vorticity patterns. An important advantage of the space-averaged wind was that it changed more slowly than the observed wind pattern. Since vorticity patterns are related to surface weather through clouds, precipitation, and thermal advection, space-averaged 500-mb wind was also considered a potentially useful advection wind vector.[2] In still later tests,[4] (Muench and Chishlom: 1985) the space-averaged winds produced the best 1-15 hour forecasts for most of the parameters.

While Eq. (2) can be used to predict the complete horizontal fields of Q at future times, it can also be used in a quasi-Lagrangian form to make simple local forecasts with high temporal resolution. For a forecast at the point $x = 0$, $y = 0$, one can use components $u*$ and $v*$ to compute $\Delta x = -u*\Delta t$ and $\Delta y = -v*\Delta t$. The value of Q at the point Δx and Δy is the forecast at time Δt. Successive iterations yield additional forecasts, each one Δt further into the future.

Contrary to expectations, the first quantitative test of the advective forecast technique[2] showed little, if any skill relative to persistence or no-change forecasts. These forecasts included cloud cover, visibility, surface wind vector, and dewpoint for periods out to 15 hours. A diagnosis revealed several problems in the procedure used, as well as the concept:

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1. Muench, H.S. (1981) *Short-Range Forecasting of Cloudiness and Precipitation Through Extrapolation of GOES Imagery*, AFGL-TR-81-0218, AD A108678.
2. Muench, H.S. (1983) *Experiments in Ojective Weather Forecasting Using Upper Level Steering*, AFGL-TR-83-0328, AD A143393.
3. Fjortoft, R. (1952) On a Numerical Method of Integrating the Barotropic Vorticity Equation, *Tellus* **4**:179-194.
4. Muench, H.S. and Chisholm, D.A. (1985) *Aviation Weather Forecasts Based on Advection: Experiments Using Modified Initial Conditions and Improved Analyses*, AFGL-TR-85-0011, AD A160369.

(1) The test was performed on the AFGL McIDAS system, using a one-degree latitude-longitude grid spacing, and using a single-pass Cressman objective analysis, which tends to over-smooth in data-rich areas.

(2) The processing did not include any error checking or quality control.

(3) Orography (for example, the Appalachian Mountains) often creates stationary weather patterns that would create errors if "advected."

(4) The advection procedure as formulated in Eq. (2) did not include the daily solar heating cycle, which strongly affects surface temperature, wind speed, visibility and height of low clouds.

To counter these problems, variations in the advection formula were created to produce "change advection" and "diurnal modification." A $\frac{1}{2}$ degree latitude-longitude, 3-pass Barnes-type analysis procedure was coded and an interactive error checking procedure (wind, temperature, and dewpoint) was introduced. Another change was the use of a procedure to "adjust" or "normalize" station data to reduce effects of altitude and instrument exposure, using monthly-mean temperature, dewpoint, wind speed and upper-air data.

These innovations were tested on regularly-spaced test cases for March 1983[2] and the skill scores relative to persistence improved to about +0.05 to +0.30 for most of the variables forecast (particularly for the 3 - 6 hour period). Some qualitative results of this experiment are summarized in Table 1. Overall, the results of the experiment were encouraging in that positive skill scores relative to

Table 1. Results of Forecast Experiments with March 1983 Data Base: Changes Relative to Simple 700-mb Advection

Better Forecasts	Worse Forecasts
Change-advection (0 - 3 hours)	Change-advection (5 - 15 hours)
700 - 500 mb space-averaged flow	850 - 300 mb vertically integrated flow
500 mb space-averaged flow	
850 mb flow, double advection (temperature and dewpoint)	850 mb flow (double advection) (clouds, visibility, winds)
Modificaton for diurnal changes	
Adjustment of initial data (winds, dewpoint)	
0.5-degree Barnes-type analyses (clouds, temperature using change advection)	0.5-degree Barnes-type analyses (wind, visibility)

persistence were achieved. Experience with other forms of guidance forecasts indicates that scores of +0.20 or more are necessary to gain forecaster acceptance as "useful."

2. TECHNIQUE DEVELOPMENT STRATEGY

The long-term objective of the advective forecast technique development has been towards the implementation of a terminal forecast technique in the Air Force Automated Weather Distribution System (AWDS). AWDS is a computer-based interactive graphics work station capability to be

deployed at base weather stations in the near future. Before such implementation could be recommended, some additional development and testing would be needed, followed by real-time tests and demonstrations on the AFGL Interactive Meteorological System - AIMS. (At the time this effort was planned, AIMS was being developed to supersede McIDAS).

The major development needed was to incorporate satellite and radar data into the forecast process, since such data are known to be useful in short-range forecasting. Satellite data could be expected to improve the analyses of cloud cover and could also be used to specify precipitation rate.[1] The GOES images would be available from the AFGL McIDAS at half-hour intervals for specifiable areas and resolutions. Manually-Digitized-Radar (MDR) data were routinely entered into the McIDAS data base, but unfortunately, radar equipment outages and communications problems often resulted in gaps in radar coverage. In addition, the McIDAS radar data base did not allow one to distinguish between "no echoes" and missing data.

Previous tests of the advection technique had all been made with an initial surface data time of either 0300 UT (10 PM EST) or 1500 UT (10 AM EST), and with upper air data from 0000 UT or 1200 UT (and assuming winds aloft remained constant with time). Forecasts could also be made from later initial surface data, simulating updates with more current data, but there would be increasing concerns about forecast degradation due to the advection flow changing with time. Tests of the value of such updates would be desirable.

The local "adjustment" or "normalization" made in the most recent tests[4] had made an improvement only for the dewpoint forecasts (and, to a small extent, for wind forecasts). There appeared to be a problem with the temperature adjustment routine that would need correction. Also, it was desirable to have a more direct means to obtain adjustments for these and other variables as well. One procedure would be to assume that the monthly mean 700-mb flow describes the overall motion of air masses and weather systems, and all stations along a streamline should have the same mean temperatures, dewpoints, wind speeds, and frequencies of cloud amount, ceiling, and visibility categories. This would be simpler than the local adjustment procedure that had been previously used.

Table 1 indicates that increasing analysis resolution produced mixed results among the various forecast parameters, sometimes better, sometimes worse. One interpretation was that for some parameters (visibility, ceiling, wind) the smaller scale disturbances were largely orographic (stationary) or short-lived, and added resolution may have actually degraded the forecasts. It is also possible that the bilinear interpolation procedure used in both the Barnes analysis and in the advection forecasts procedures resulted in distortions of the small scale features. A biquadratic routine could be easily derived and installed in the analysis routine to test for improvement in the analyses.

The strategy for modifying the advection technique are expanding and the testing can be summarized as follows:

(a) Add satellite information
(b) Improve the local adjustment procedure
(c) Test a biquadratic interpolation
(d) Test "updates" made more than three hours after radiosonde time.

3. TEST PLANS FOR MARCH 1984 DATA BASE

March 1984 was selected as a data gathering period for the next series of forecast tests since March typically has a wide variety of weather conditions, and the sun is high enough for good visible channel imagery from GOES. Balancing the task of data processing and the desire for large numbers of forecasts and verification, four cases each week were scheduled, 36 hours apart, two starting at 1200 UT and two at 0000 UT, making 8 daytime and 8 nightime forecast cases. Eight parameters would be forecast: cloud cover, ceiling height, visibility, rainfall rate, temperature, dewpoint, and u- and v-components of wind. Forecasts would be made at 30 locations (see Figure 1) out to 15 hours, starting at 1500, 1800, and 2100 UT (daytime) or 0300, 0600, and 0900 UT (nighttime). As in previous experiments, the natural logarithm (ln) of ceiling height, visibility and rainfall rate would be used in the analyses, forecasts, and verifications to represent the wide range of values for these parameters. Since hourly precipitation rates are not a normal part of aviation weather observations, they would be deduced from "present weather" (using visibility as a check on precipitation intensity) for the analysis, but observed hourly precipitation would be used for verification. Also, as in past experiments,[2,4] forecasts would be made for different combinations of enhancement (diurnal modification, change advection) and of advection flow (850-, 700-, and 500-mb winds).

The data processing, analysis and forecast procedure is outlined in Figure 2. Briefly, there would be a separate data extraction program for each magnetic tape data source (satellite, surface observations - "SVCA", upper air observations - "RAOB", and Model-Output-Statistics - "MOS"). The extracted data (except MOS) would be put in separate data files, one file for each case. Next, objective analyses would be performed on each data set, with separate runs for each option (with/without local adjustment, with/without satellite data), producing sets of analyses for each case. Then the analyses would be used to produce forecasts, hour-by-hour out to 15 hours for each of the 30 stations, at each of the three initial times. Finally, all forecasts would be compared to verifying observations, to compute errors and skill scores relative to persistence. A separate, but similar procedure would be used for the MOS forecasts, but programs for analysis and forecast would obviously not be needed. More details on the programs that were written can be found in the Appendix.

4. IMPLEMENTATION AND PROBLEMS

The upper air and surface observations were easily obtained by making copies of the "100-hour" McIDAS data files that were routinely copied onto archive tapes. The satellite data required that a special procedure be set up to schedule reception of imagery data and to place the data on magnetic tapes. For daytime cases, 4-km resolution (visible and IR) images centered at 39N, 80W (near Elkins, WV) were recorded at 12, 15, 18, and 21 UT, with 1-km images centered at 41N, 76W recorded at intervening half-hour times. The 1-km images were saved in anticipation that higher resolution, shorter time period experiments would also be made, and the area covered the dense airways network from Washington, DC to Boston, MA. At night, when visible channel imagery is not available, 4-km IR images were recorded at half-hourly intervals from 0000 UT to 0630 UT, centered at 39N, 80W. A complication in the recording operation occurred on Thursday, 29 March, when a major snowstorm struck the area, sending employees home early and closing AFGL the following day - half the data for

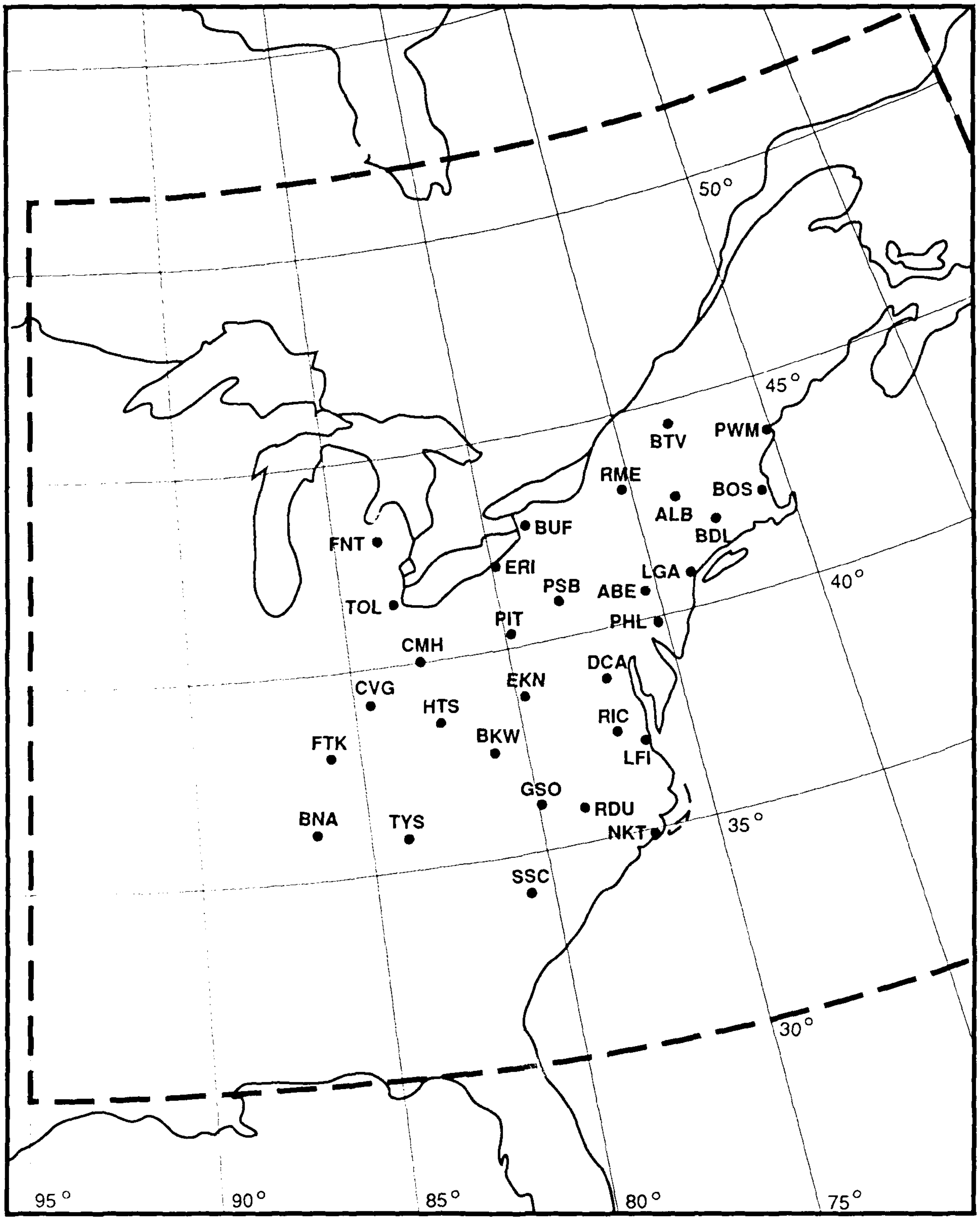

Figure 1. Forecast Sites and Area in Objective Analysis

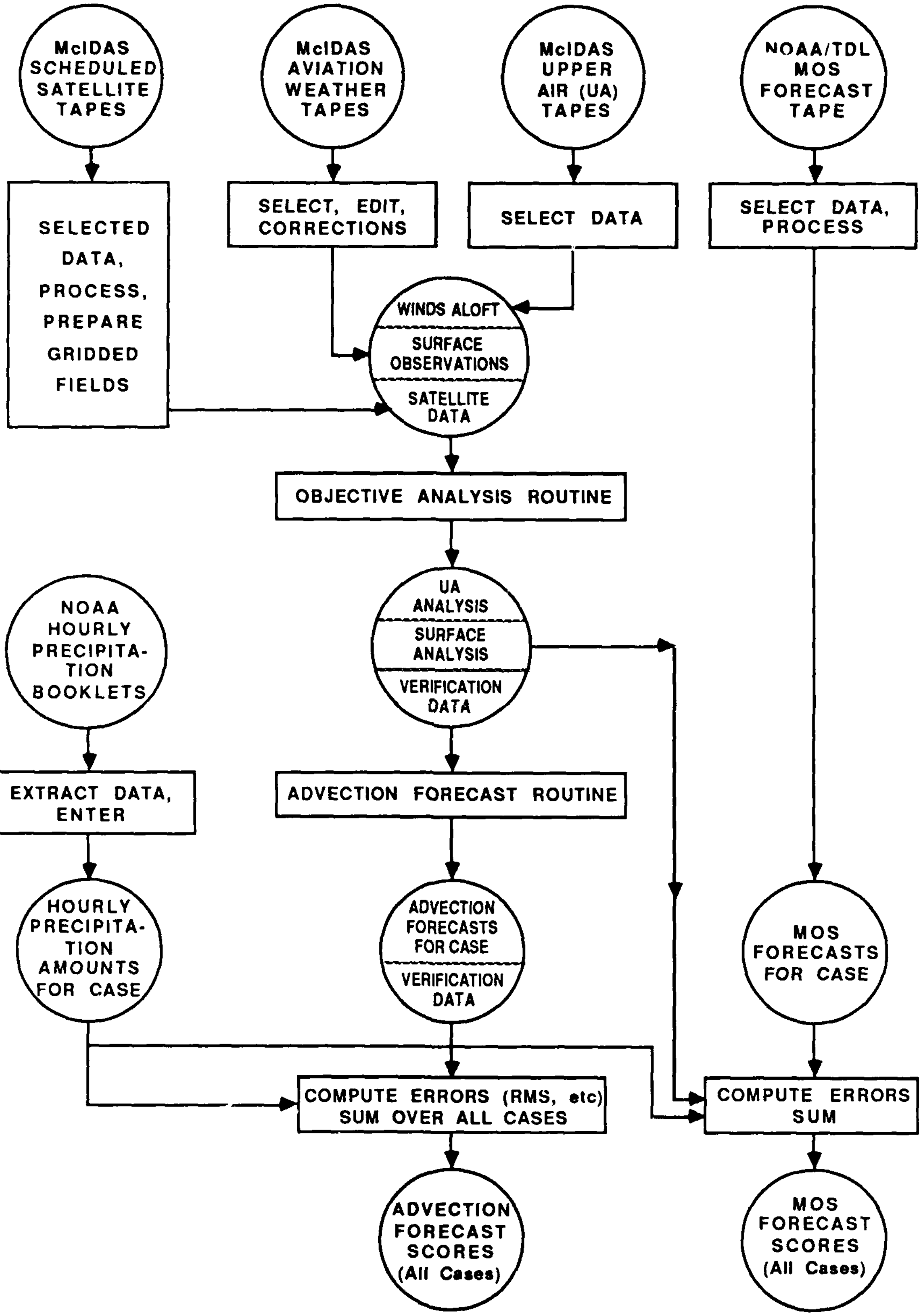

Figure 2. Procedure for Preparation and Verification of Forecasts

one case and all the data for the following case were lost. This required that two makeup cases be scheduled for the following week. Unfortunately, this was the type of storm when satellite data can be quite useful.

National Weather Service MOS forecasts were obtained through the AWS Staff Meteorologist at NOAA/TDL. They provided us a tape of the MOS forecasts for 30 stations, 00 and 12 UT, over the five-week test period. Unexpected benefits were that we could choose station forecasts not available on the FAA-604 line serving McIDAS, and the probabilities were to three decimal place accuracy instead of the one place accuracy found in the "FOUS" format.[5]

While the data gathering procedure went according to plan (except for the snowstorm), other constraints limited this forecast test to the daytime cases when complete satellite data (visible and IR) were available. Further complications developed as the cases were being processed, when images were found to be missing in the middle of two daytime cases and the MOS forecasts were not available from the 12th to the 20th. These data gaps limited the experiment sample to four cases. Fortunately, a good variety of weather occurred on the four scheduled cases. However, to improve the size of the forecast data base, we combined the errors of three successive hours, presenting scores for forecast of 1, 3, 6, 9, 12, 15 hours (for example, 2, 3, 4, for three-hour forecast). Also, while scores were computed separately for forecasts from 15, 18, and 21 UT data, most of the attention will be placed on the combined scores for all three initial times.

5. RESULTS AND DISCUSSION

Before presenting the results, two clarifications are in order. First, there is a question of representativeness to be addressed, since only four cases were run, compared to 12 for the March 83 based experiments. Fortunately, the present experiment included 30 stations rather than 12 as before and three initial times rather than one, making 360 forecasts for any time (0 - 15 hours) compared to 144 in prior experiments. Of course, if all four cases happened to have unusually fair weather or unusually stormy weather, the sample would be biased. Some statistics from the objective analysis routines are shown in Table 2, for the two March experiments. For this table, the March 84 data were selected to best match the March 83 analyses in terms of grid-length and local adjustment (or not). The spatial variability of the two data sets (first two columns) were similar overall, but there was more spatial variability for temperature, dewpoint, and vector wind in the March 84 data set, and less variability for ceiling and visibility. The "analysis error" represents the inability to specify the observation through interpolation of gridded data to the observation site at the 30 forecast locations. These analysis errors were generally smaller for the March 84 analyses, in spite of greater spatial variability for some parameters. As a result, a higher percentage of the spatial variance was resolved (last two columns) in the March 84 analyses. One should note that for both years the resolved variance differed among parameters, highest for temperature and dewpoint and lowest for ceiling and visibility. As we shall see later, the resolved variance does impact on forecast skill.

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5. NOAA/NWS (1980) The FOUS (FO12) Bulletin, NWS Technical Procedures Bulletin, Series No. 293.

Table 2. Comparison of March 83 and March 84 Objective Analysis Properties

	Spatial Variability		Analysis Error		Variance Resolved	
Parameter Units	March 83	March 84	March 83	March 84	March 83	March 84
Cloud Cover	±0.33	±0.35	±0.10	±0.10	.908	.918
Ln Ceiling Ht	±1.57	±1.17	±0.44	±0.41	.921	.877
Ln Visibility	±0.99	±0.88	±0.40	±0.33	.836	.859
Ln Rainfall Rate	-----	±1.22	-----	±0.74	----	.632
Temperature (F)	±6.16	±7.92	±0.96	±0.66	.976	.993
Dewpoint (F)	±5.65	±7.19	±1.24	±0.94	.952	.983
Vector Wind (m/s)	±4.90	±5.48	±2.01	±1.65	.832	.909

The second point is that precipitation becomes difficult to forecast and verify because the rate of accumulation essentially has a discontinuity at zero - negative values cannot occur. To avoid problems, precipitation rate errors were computed only when precipitation was both forecast and observed (this reduced the sample size to about 12 percent of the total sample). Also, a separate tabulation was made for yes/no forecasts of >0.01 in/hr (six-hour for MOS) and "percent correct" scores were computed. Ceiling height was also verified only when >0.5 cloud cover was both forecast and observed (about 60 percent of the time).

The verification programs generated many pages of summarized data, some of which will be presented here to at least partially answer specific questions in Section three. These questions relate to:

(a) *Degradation of advection forecast updates*

(b) Value of new local adjustment procedure

(c) Value of satellite data

(d) Value of bi-quadratic interpolation

One question posed was whether advection forecast skill was degraded when making an update forecast using more current surface weather observations with the old upper air advection winds. To answer this, the root-mean-square (RMS) errors and skill scores (relative to persistence) were computed for all cases, all stations, all forecast times combined, for each of the three initial times - 1500 UT, 1800 UT, and 2100 UT. A single advection flow-technique that produced the best overall scores for each parameter was used. The resulting RMS errors and skill scores are shown in Table 3. One sees that the RMS errors are quite similar for forecasts following each of the initial times. If there is any trend present, errors for the later forecast look slightly lower than for the earliest forecast, the reverse of what might be expected (solar heating in mid-day may be disrupting advection processes). The skill scores are based on RMS errors of both the advection technique and persistence. Since there are some diurnal variations in persistence errors, the skill scores are better at 2100 UT for some parameters and worse for others. The main conclusion of this test is that there was no obvious degradation in accuracy by updating the forecast with current aviation observations together with "old" advection winds (and there would be operational advantages). Also, with temporal difference so small, we decided to combine the results from 1500 UT, 1800 UT, and 2100 UT to increase sample size, rather than treating them separately in subsequent presentations.

Table 3. Comparison of RMS Errors and Skill Scores for Forecasts Made from 1500 UT, 1800 UT and 2100 UT data

Parameter	Root-Mean-Square Errors 1500 UT	1800 UT	2100 UT	Skill Scores 1500 UT	1800 UT	2100 UT
Cloud Cover (700 mb Advection)	±0.30	±0.29	±0.29	+0.10	+0.05	+0.09
Ln Ceiling Ht (500 mb Advection)	±1.15	±1.06	±0.98	+0.21	+0.15	+0.14
Ln Visibility (500 mb Advection)	±0.77	±0.73	±0.69	+0.26	+0.18	+0.09
Ln Rainfall Rate (700 mb Advection)	±0.81	±0.83	±0.83	-0.10	+0.04	+0.12
Rainfall Pct Cor. (500 mb Ch-Advect)	83%	86%	85%	+0.20	+0.19	+0.18
Temperature (C) (500 mb Adv+Diurn)	±3.46	±3.29	±3.24	+0.02	+0.20	+0.40
Dewpoint (C) (500 mb Advection)	±3.20	±3.18	±3.24	+0.19	+0.18	+0.11
Vector Wind (m/s) (500 mb Advection)	±4.19	±4.22	±4.10	+0.18	+0.22	+0.26

In the second option of the objective analysis procedure, local adjustments were made to the hourly observations and then a running-time-mean (RTM) was computed (to reduce high frequency "noise"), all prior to analysis. After the advection forecasts were completed, the values were then adjusted back to return to local conditions by reversing adjustment logic, before computing the errors. Effects of this preprocessing can be seen in Table 4, where the RMS errors for two different options are

Table 4. Effects of Local Adjustment (Adj.) and Running-Time-Mean (RTM) on RMS Errors, for Advection and Change-Advection Forecasts

	Advection no Adj. no RTM	Adj. RTM	Pct. Improv.	Change-Advection no Adj. no RTM	Adj. RTM	Pct. Improv.
Cloud Cover	± .297	± .298	-0%	± .300	± .302	- 0%
Ln Ceiling	±1.07	±1.09	-2%	±1.25	±1.20	+ 4%
Ln Visibility	± .732	± .731	+0%	± .967	± .956	+ 1%
Ln Rainfall Rate	±1.07	±1.04	+4%	±1.62	±1.32	+19%
Rainfall Pct Wrong	.178	.166	+7%	.161	.154	+ 4%
Temperature (C)	±3.34	±3.07	+8%	±4.34	±4.24	+ 2%
Dewpoint (C)	±3.21	±3.10	+4%	±3.84	±3.77	+ 2%

compared: no-adjustment-no-RTM and with-adjustment with-RTM. The differences in the RMS errors divided by the RMS error for the first option gives the percent improvement found in the third

and sixth columns. In column three, the improvements vary from -2 percent (ceiling) to +8 percent (temperature). In the change-advection forecasts, a difference is taken between analyzed values separated by three hours in time, and 1/3 this value used at each one-hour forecast step. In the time differencing, the local adjustment is, for the most part, removed and the difference in the RMS errors for the two options primarily reflects the effects of the RTM. In the last column, we see that with the exception of rainfall rate, the introduction of RTM produced small positive improvement (reduction of error). For rainfall rate, the improvement looked suspiciously large and might be considered an anomaly due to small sample size. However, looking at errors for the three different initial times (not shown), the improvements ranged from +10 to +23 percent, and would appear to represent an important reduction in "noise."

If we compare the two sets of percentage improvement, we should get some idea of what was gained (lost) by the local adjustment procedure by itself. If the adjustments did produce a gain, the improvement of advection scores should be greater than the improvement of change-advection. For temperature and dew point, adjustment did produce gains. For the first four paramaters (clouds, ceiling, visibility, and rainfall rate) adjustment seems to have hurt more than helped. In truth, this was the first test of adjustment for these parameters and the approaches may have been overly simple and data sample too small to contain sufficient numbers of extreme conditions. Similar scores for vector wind were not presented here, as a coding error in the adjustment routine produced unpredictable, though small errors. Overall, the RTM procedure produces beneficial results but the adjustment procedure for some parameters needs further work.

The third option in the objective analysis procedure introduced the satellite estimates of cloud cover and rainfall rate, as well as using the local adjustment and RTM routines. (This was hoped to be the "ultimate" forecast scheme.) By comparing the errors for the second and third options, as presented in Table 5, we can start to assess the value of the satellite data. At first glance one could be

Table 5. Effect of Satellite-Based Cloud Cover and Rainfall Rate Estimates on RMS Errors of Advection and Change-Advection Forecasts

	Advection			Change Advection		
	No Satellite	With Satellite	Pct. Improv.	No Satellite	With Satellite	Pct. Improv.
Cloud Cover	± .298	± .310	-4%	± .302	± .305	-1%
Rainfall Rate	±1.04	± .986	+5%	±1.32	±1.36	-3%
Rainfall, Wrong	0.166	0.165	+1%	0.154	0.151	+2%
Temperature (C)	±3.07	±3.05	+1%	±4.24	±4.19	+1%

discouraged, as the improvements are small and in several instances negative. That they should be small is in part due to conservative weighting we chose to give to the satellite estimates of rainfall rate and cloud cover. For example, the satellite rainfall rate estimate had little effect if there was one surface station within 70 km of a grid point or three stations within 110 km (similarly, 90 km and 140 km for cloud cover). Station density over most of the analyzed area (30-52N, 61-95W) was dense, limiting the impact of the satellite estimates primarily to the western Atlantic and southern Canada portion of this area. In addition, the satellite estimates may well be highly correlated to the surface observations and hence add little independent information. The small decrease in rainfall rate error

by using the satellite estimates is encouraging, though the data sample size is small. For change advection, errors increased, and this may indicate the presence of high frequency noise, which was reduced when using only station data through the RTMs. Perhaps rather than using one satellite image every three hours, we should derive estimates of rainfall rate from each half-hour set of GOES images and then use the RTM procedure on these estimates.

The increase in errors (negative improvement) for cloud amount might have been anticipated, as only the visible channel data were used to specify cloud cover, probably underestimating the coverage of high clouds. A more complete algorithm would also include IR channel data, which is better for detecting high, relatively thin clouds. Since the temperature forecast routine with the most skill does use forecast cloud cover in the diurnal cycle computations, there can be an impact from using satellite data in the forecasts. Table 5 indicates this is a very small but positive impact, perhaps suggesting the satellite data improved forecasts of low clouds which affect temperature more, while degrading forecasts of high clouds. In order to get maximum use of satellite data to predict the diurnal cycle changes, cloud density and not just cloud amount should be estimated and forecast (a "normalized reflectivity" is available from the satellite data processing routine).

The present status of advection forecast skill, as determined from the March 84 experiment, is shown in Figures 3 through 10. These figures present the skill score (relative to persistence) as a function of forecast time (projection), based on "best combination" prediction techniques- typically, change-advection for 1 - 3 hours and basic advection for 3 - 15 hours. As pointed out previously,[4] analysis error limits forecast skill score (for moving patterns) and a maximum skill score S_x is determined by

$$S_x = 1 - \varepsilon_a / P \tag{3}$$

where ε_a is the RMS analysis error and P the RMS persistence error. For change-advection, the corresponding maximum is:

$$S_x = 1 - \sqrt{2t/\gamma}\, \varepsilon_a / P \tag{4}$$

where t is the forecast projection (hours) and γ is time interval used in the change (three hours). As t goes beyond the time interval (three hours), the change advection forecasts degrade relative to the basic advection forecasts. The maximum skill score (basic advection) and the "MOS" (NOAA/NWS Model-Output-Statistics forecast) skill scores are also shown in these figures.

The first point to make is that these diagrams are very similar to those presented in the report on the March 83 experiments.[4] For example:

(a) The "best combination" advection flows and techniques are, for most parameters, the same.

(b) The best combination scores are generally better than MOS from 1 to sometime between 3 and 6 hours, and generally better than persistence from 1 to 15 hours.

(c) The overall skill scores for the subjective parameters (clouds, ceiling, and visibility) are noticeably lower than for the parameters measured by instruments (temperature, dewpoint, and wind).

The positive skill scores for the new parameter, rainfall rate, is encouraging (at least beyond three hours) considering that indirect present weather and satellite estimates were used in the forecast and measurements in the verification. One would like to see hourly measurements in the aviation

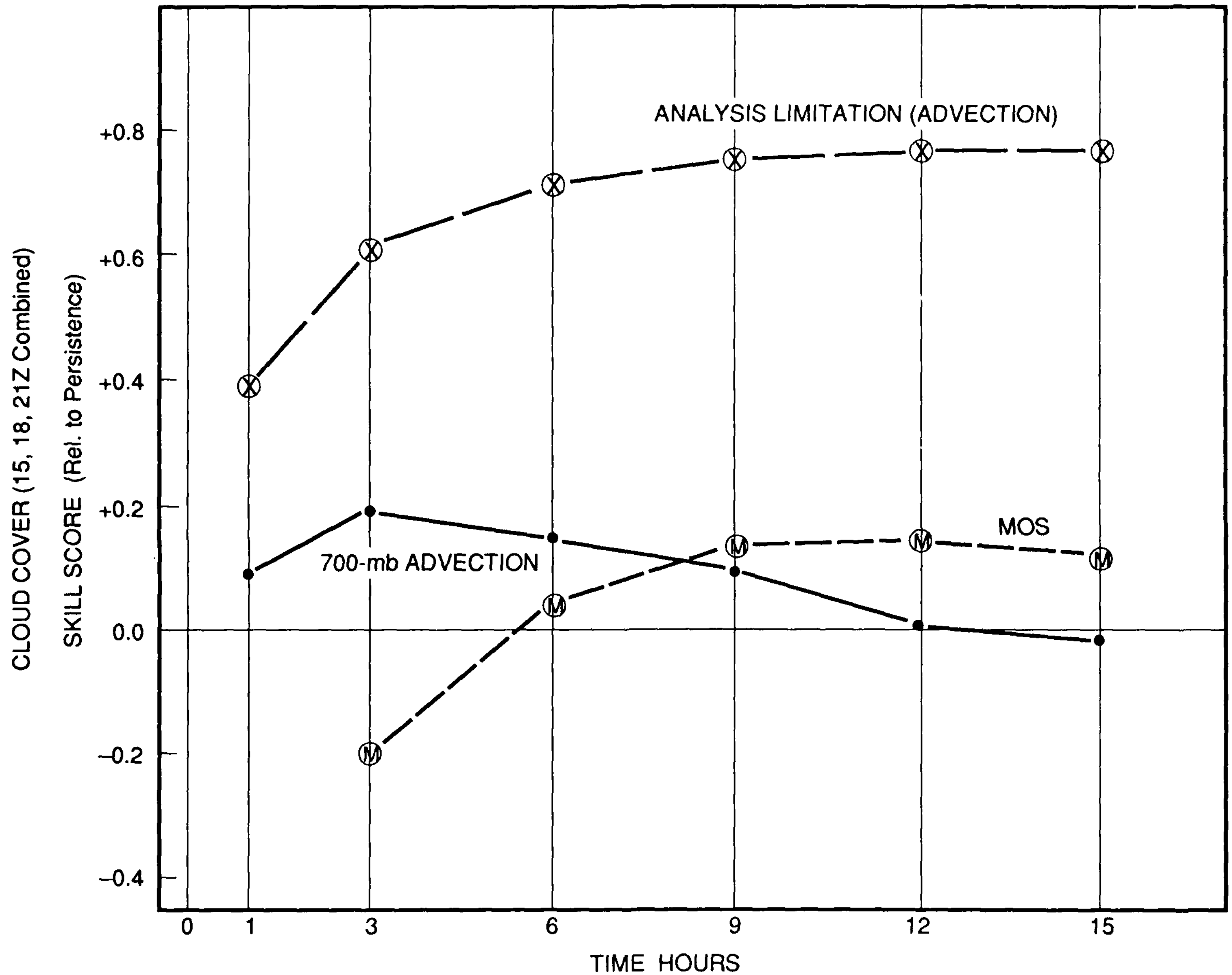

Figure 3. Forecast Scores as a Function of Time (Cloud Cover)

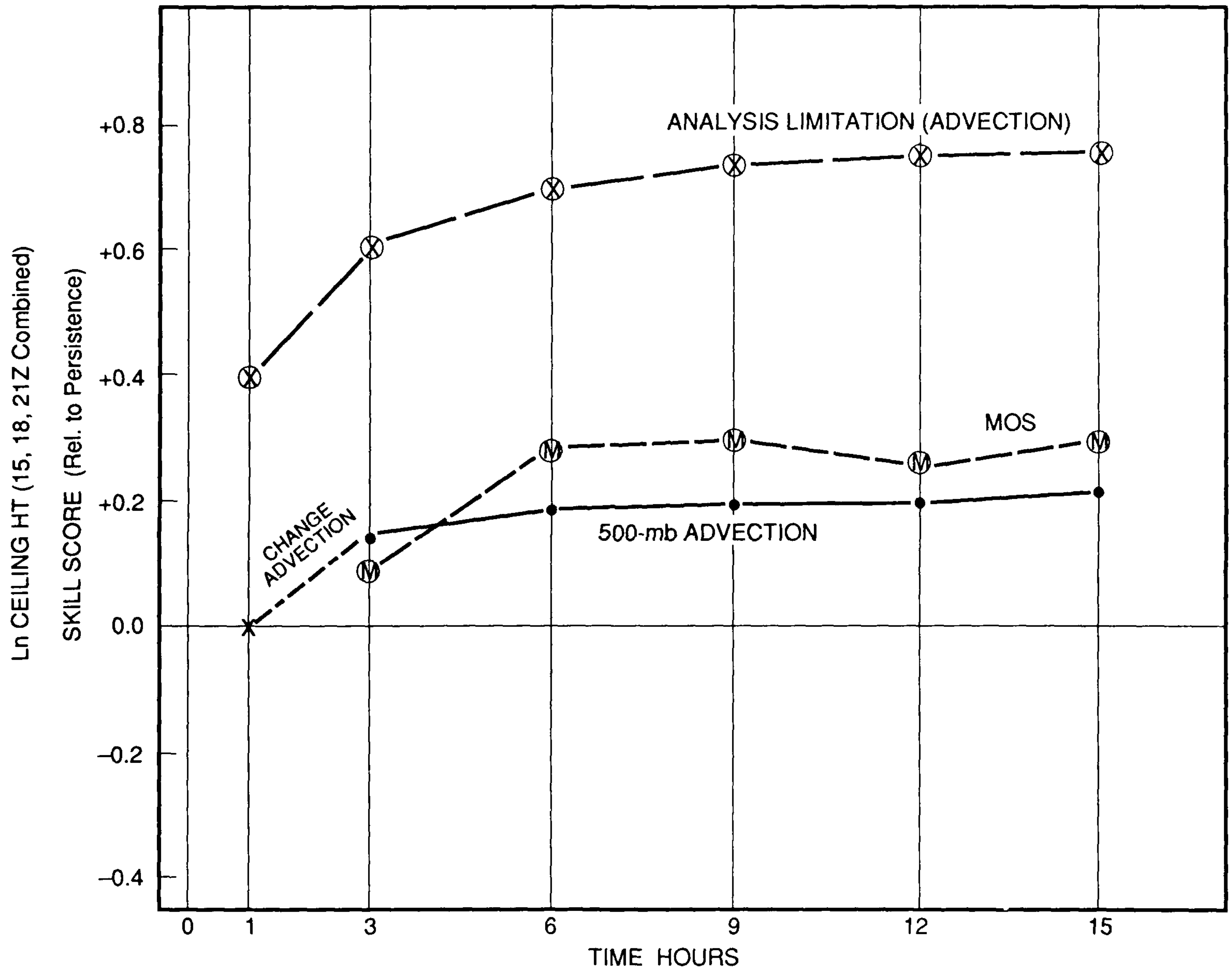

Figure 4. Forecast Scores as a Function of Time (Ln Ceiling Height)

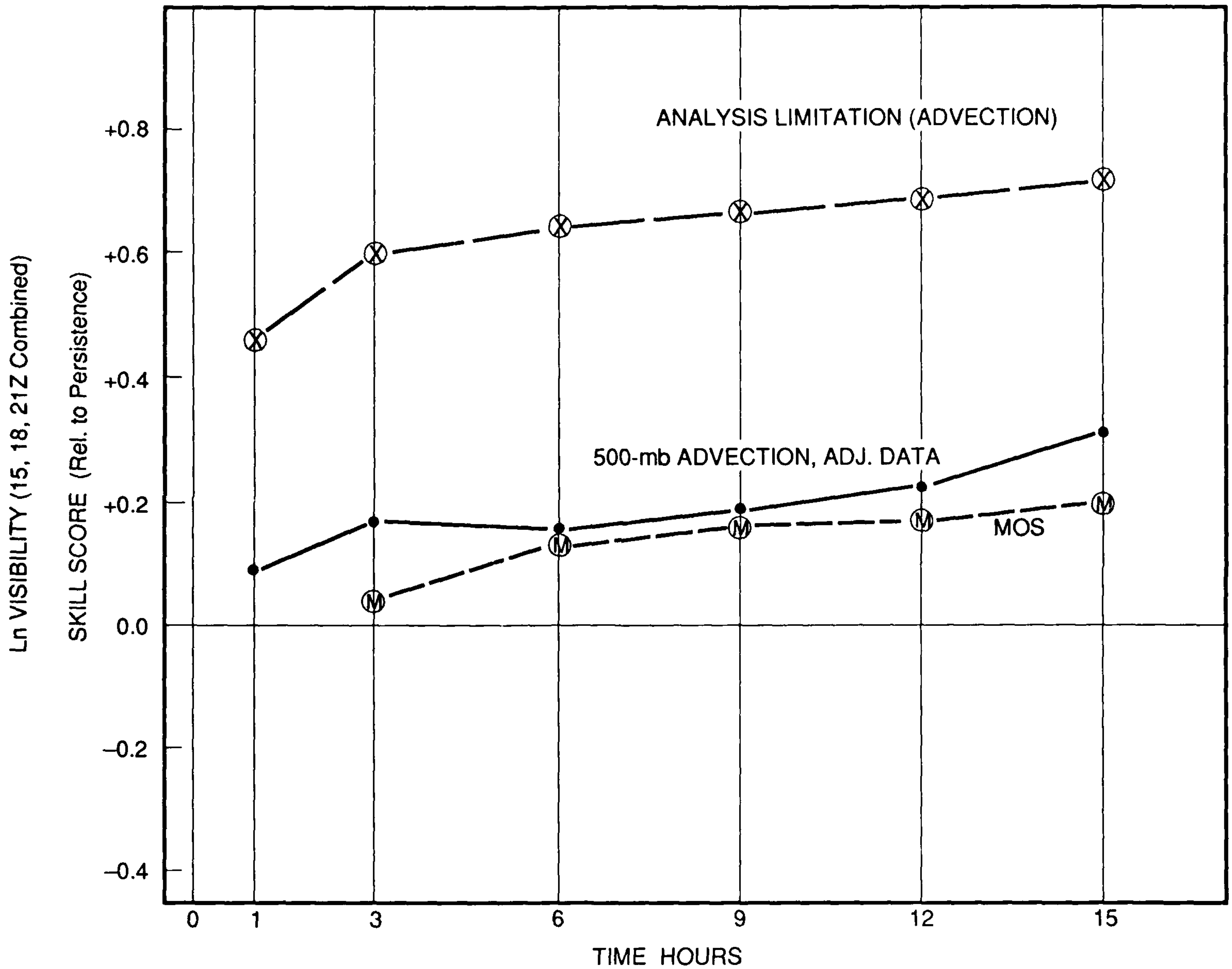

Figure 5. Forecast Scores as a Function of Time (Ln Visibility)

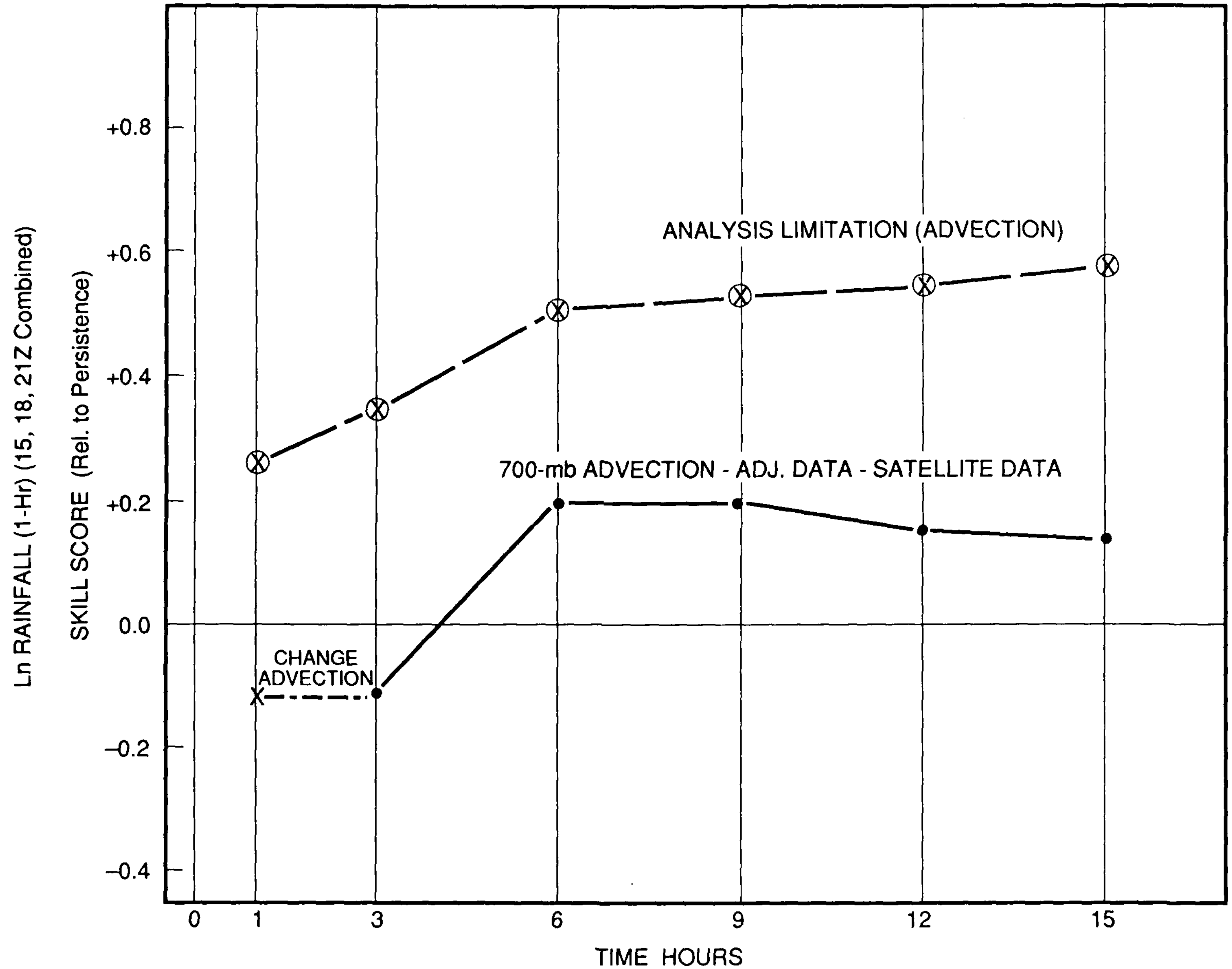

Figure 6. Forecast Scores as a Function of Time (Ln Rainfall)

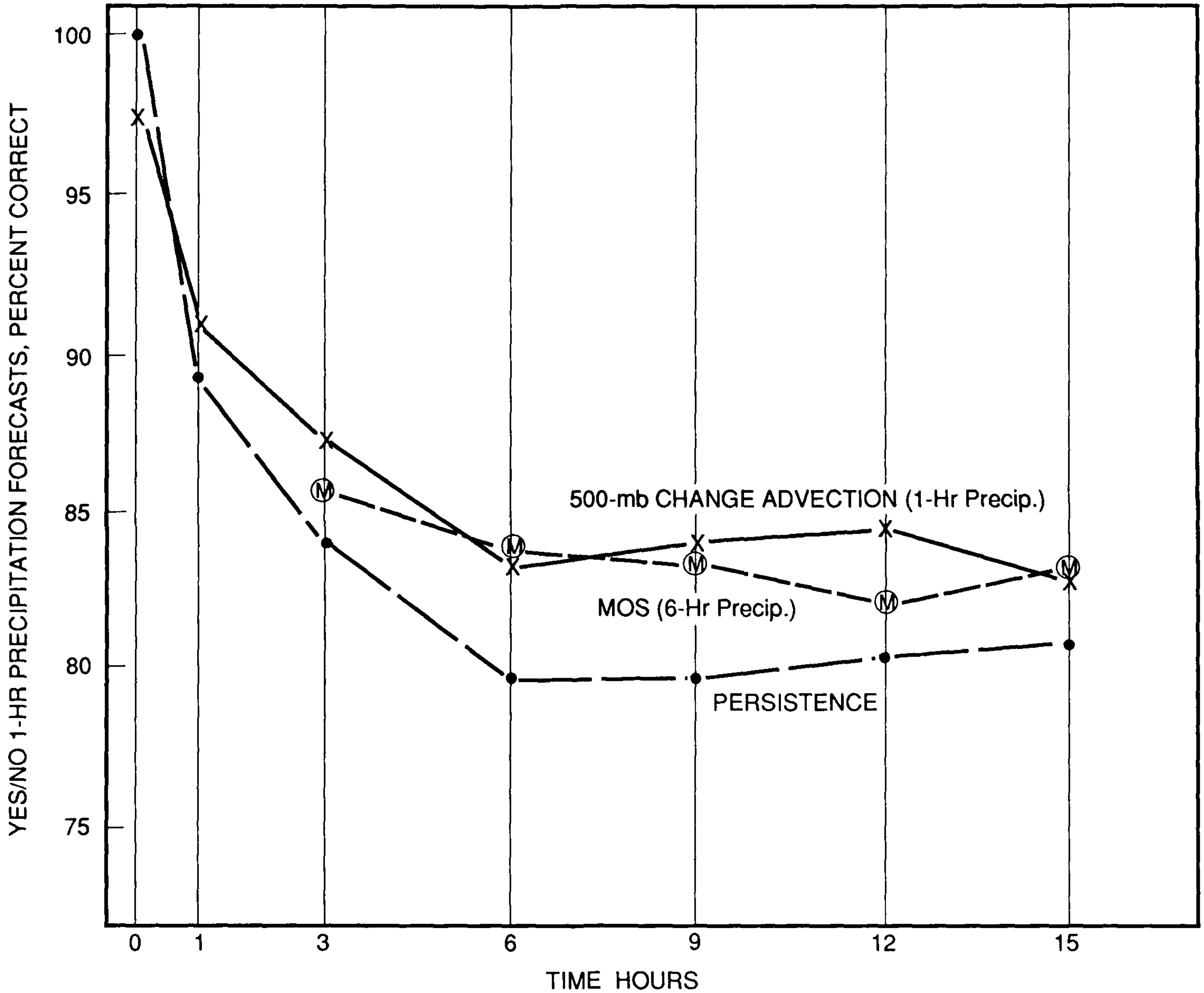

Figure 7. Forecast Scores as a Function of Time (Yes/No Precipitation Forecasts, Percent Correct)

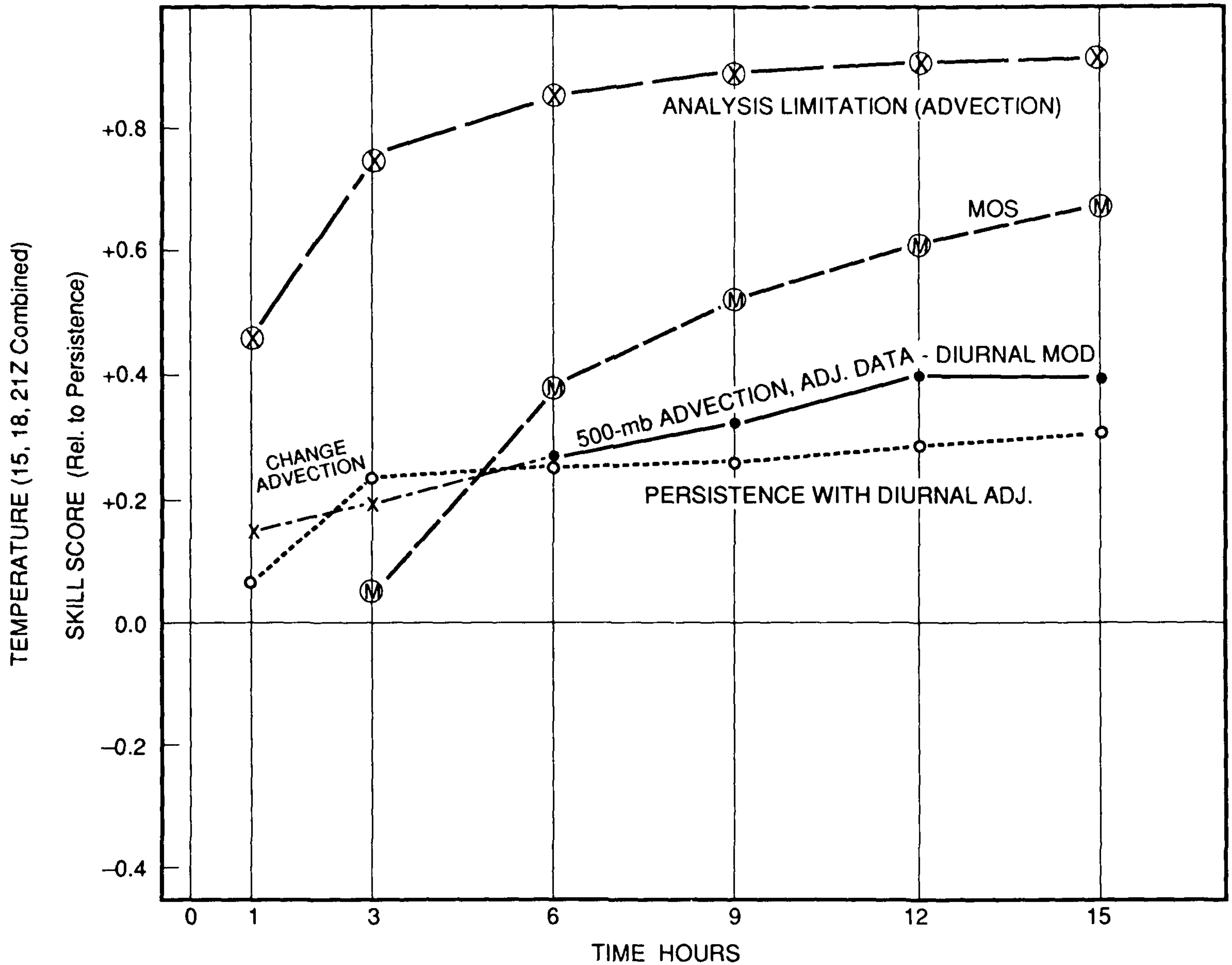

Figure 8. Forecast Scores as a Function of Time (Temperature)

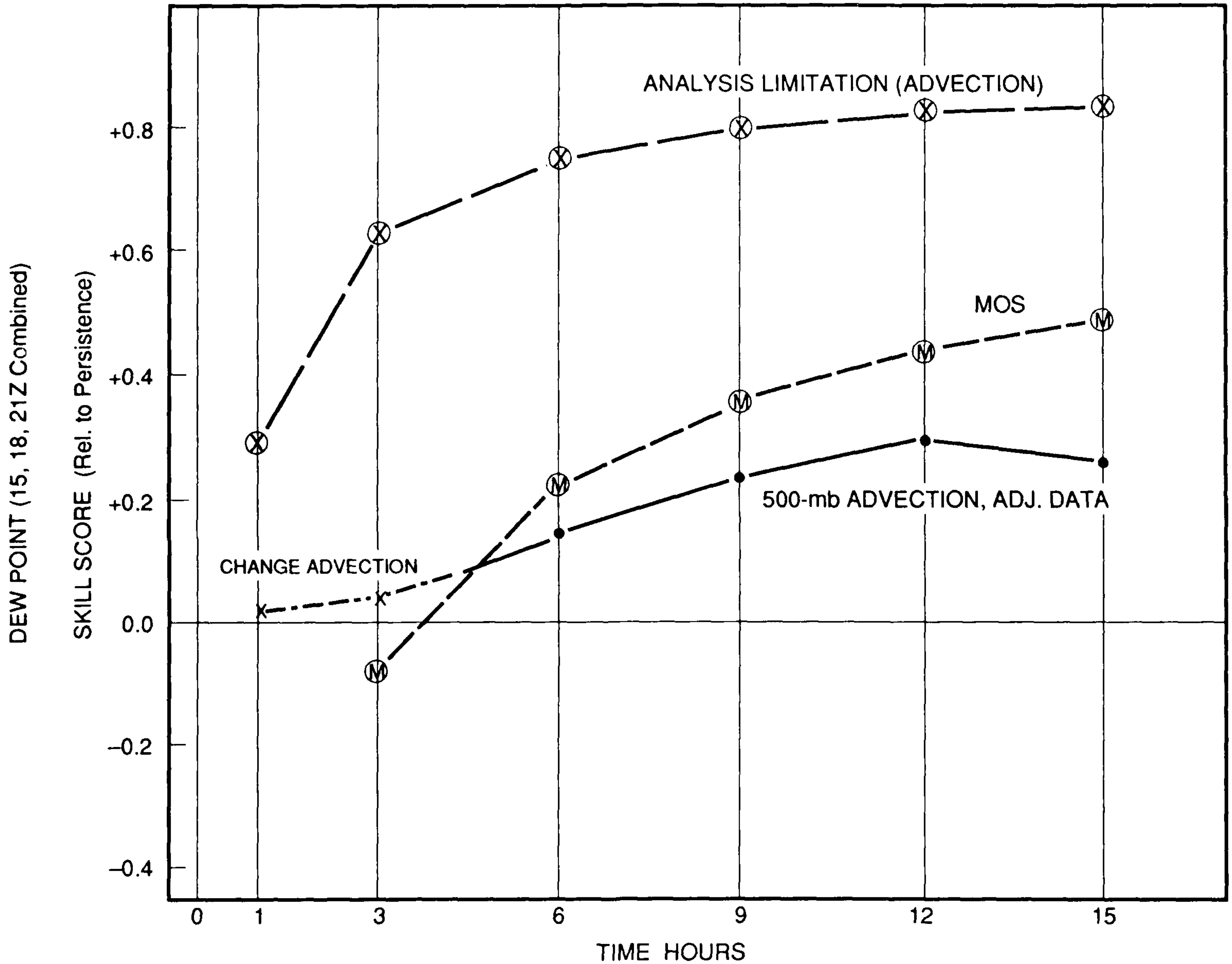

Figure 9. Forecast Scores as a Function of Time (Dew Point)

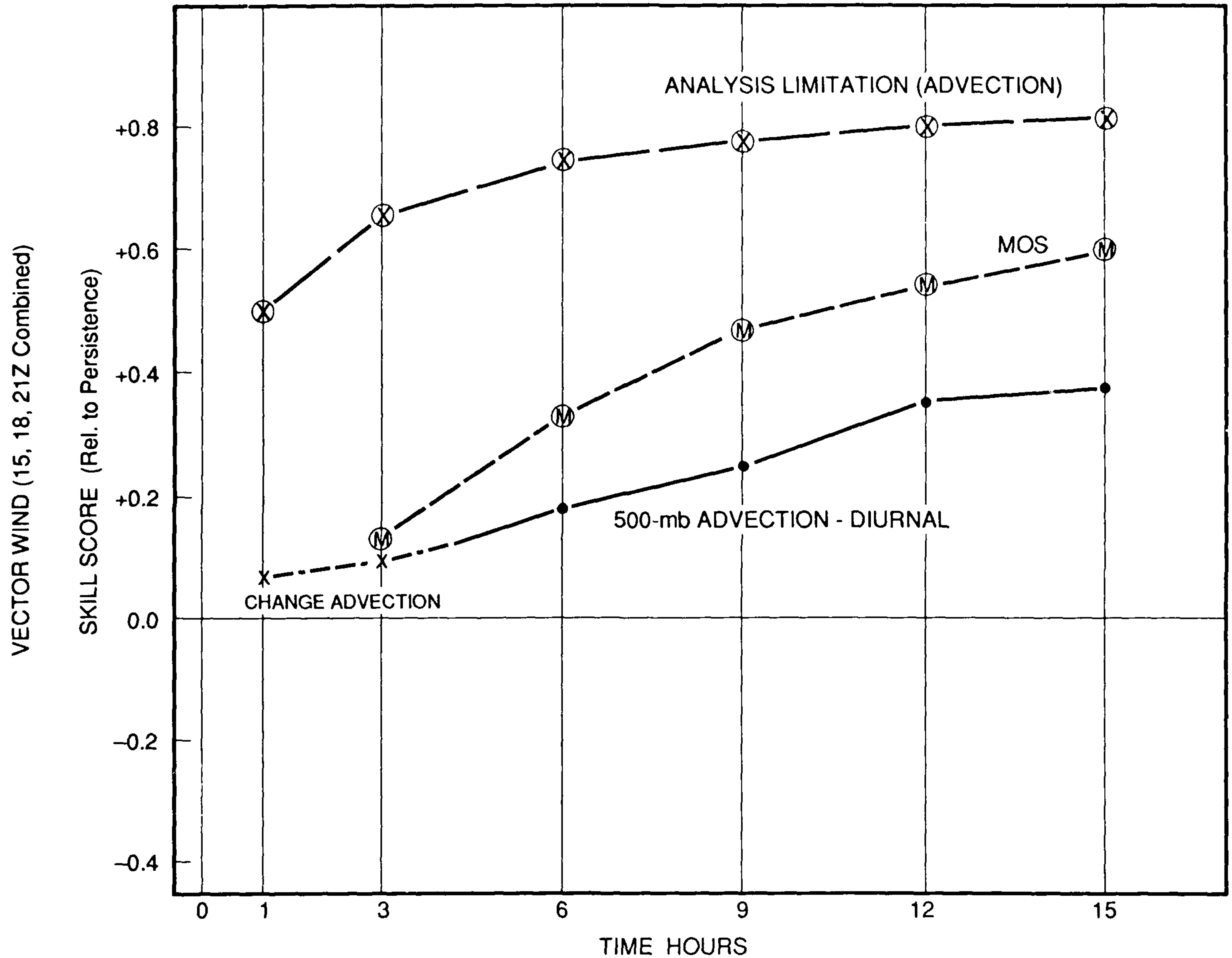

Figure 10. Forecast Scores as a Function of Time (Vector Wind)

reports and use them directly in the analyses, as this would likely lead to even more skillful (and useful) forecasts. The rainfall rate scores indicate some skill in forecasting the details within the area of precipitation, and we see improvement over persistence in the yes/no forecasts of precipitation occurrence indicating some changes in the area of precipitation are also correctly forecast. While the MOS forecasts have similar percent correct scores, there is only a 6-hour time resolution in MOS forecasts and not the 1-hour resolution of the advection forecasts.

One difference from the March 83 results should be mentioned. In this experiment, the skill scores for ceiling height were considerably higher than the earlier study (0 to +0.21 vs. -0.21 to 0). As discussed earlier in this section, the introduction of local adjustment made ceiling forecasts worse, and the RTM routine produced only a small benefit, so these changes did not account for the higher skill scores. For this experiment, error checking of ceiling was added to the editing routine and may have resulted in some forecast improvement, but the most likely explanation is that there was a difference in weather patterns of the two data sets (perhaps a longer lifetime in the March 84 disturbances).

To test its impact, the biquadratic interpolation scheme was inserted in the objective analysis program, but not in the advection forecast program. For consistency, the "analysis error" used in computing maximum skill scores was based on the bilinear interpolation used in the forecast program (the time = 0 forecast), at 30 stations. However, the analysis program using the biquadratic interpolation did compute "residual" or analysis errors using all reports (typically about 350). Table 6 shows a comparison of analysis error for the bilinear and biquadratic interpolation methods, based

Table 6. Comparison of Objective Analysis Errors for Bilinear and Biquadratic Interpolation (Based on 12 Analyses)

Parameter	Bilinear Error	Biquadratic Error	Biquadratic Improvement Pct.
Cloud Amount	.097	.088	+ 9
Ln Ceiling Ht	0.41	0.37	+10
Ln Visibility	0.33	0.31	+ 5
Temperature (C)	0.64	0.61	+ 5
Dewpoint (C)	0.94	0.88	+ 7
Vector Wind (m/s)	1.65	1.30	+21

Note: Rainfall rate was not included in this table because the verification of bilinear interpolation used measured rainfall and biquadratic interpolation did not, making interpretation of a large difference (38 percent) difficult.

on 12 objective analyses (four cases, three initial times). All parameters showed reduced error for the biquadratic interpolation, with most improvements (reduced error) about +5 to +10 percent, though somewhat higher for wind (+21 percent). Rainfall rate was not included in Figure 6, because the verification of bilinear interpolation used measured rainfall and the biquadratic did not, complicating interpretation of the difference. There was concern that it might be inconsistent to use a bilinear interpolation in the forecast procedure on gridded fields that were produced using a biquadratic interpolation in the analysis procedure. Nevertheless, the forecast errors were less for

this March 84 experiment than corresponding errors were for the March 83 experiment, which used bilinear interpolation in both analysis and forecast. We can conclude that the biquadratic interpolation procedure better fits the observations. We can speculate that, had it been used in the forecast program, it might well have further improved forecasts.

6. LIMITS AND FUTURE WORK

The advection skill scores in Figures 3 through 10 tend to run parallel to the maximum skill scores (labelled "Analysis Limitations") but are only about 30 percent as great, suggesting some relationship. As a test, maximum skill scores were computed for both advection change-advection, for 1-, 3-, and 6-hour forecasts, for all parameters, and for both the March 84 and March 83 experiments. A plot of maximum skill score vs. forecast skill score is seen in Figure 11. The relationship is fairly obvious, and the linear correlation is $r(S,_S) = +0.80$, with a best fit regression formula $S = -0.2 + 0.7\,S_X$. On one hand, this indicates that there is a reward for decreasing analysis error and thereby increasing S_X and S. Being realistic though, there is not much more room for increasing S, especially considering there are limitations due to observation "round-off," small observing errors, as well as station number and density. At best, the advection techniques for these parameters may be pushed up to the +.20 to +.35 range, which would be useful but really not impressive.

If we accept the skill scores of +.20 to +.35 as operationally attainable, this would mean RMS errors of 0.8 to 0.65 times those of persistence, which would equate to mean unpredicted change variances of 64 percent to 42 percent, or predicted variances of 36 percent to 58 percent. The question then becomes "how do we do any better?" It is important to remember that the advection flows were in general quite different than the surface winds where the parameters were observed. By using upper-level winds, we in effect were advecting the "non-advective" processes that vertically transport heat, moisture and momentum, and that form and dissipate cloud and precipitation particles. The positive skill scores occur when the nonadvective process patterns move with the weather systems in a coherent fashion, but skill vanishes when there is synoptic scale development (or decay) or if local orography modifies the nonadvective processes. The MOS forecasts have the advantage that (1) the numerical models (LFM) can correctly forecast development and decay and (2) effects of local orography are statistically included (indirectly). MOS seems to work well for temperature, dewpoint and winds, less well for other parameters. The only disadvantage is that MOS does not use the high spatial resolution hourly data, using only the hourly observation for the forecast site. In principle, the change-advection technique can extrapolate development or decay tendencies but unfortunately, any "noise" present in analyses gets amplified at prediction times past the differencing interval. While increasing this differencing interval might reduce noise, it probably should not be extended beyond three hours or an important signal will be lost.

A more rigorous approach to getting at the unpredicted variance would be through a high resolution dynamic model running within a coarser resolution model. The high resolution model would use surface parameters such as roughness, soil moisture, soil temperature appropriate to a particular airport (or other forecast site) and not to the 100-km size areas of coarser models. The model could then predict how the local boundary layer reacts to the passage and development of

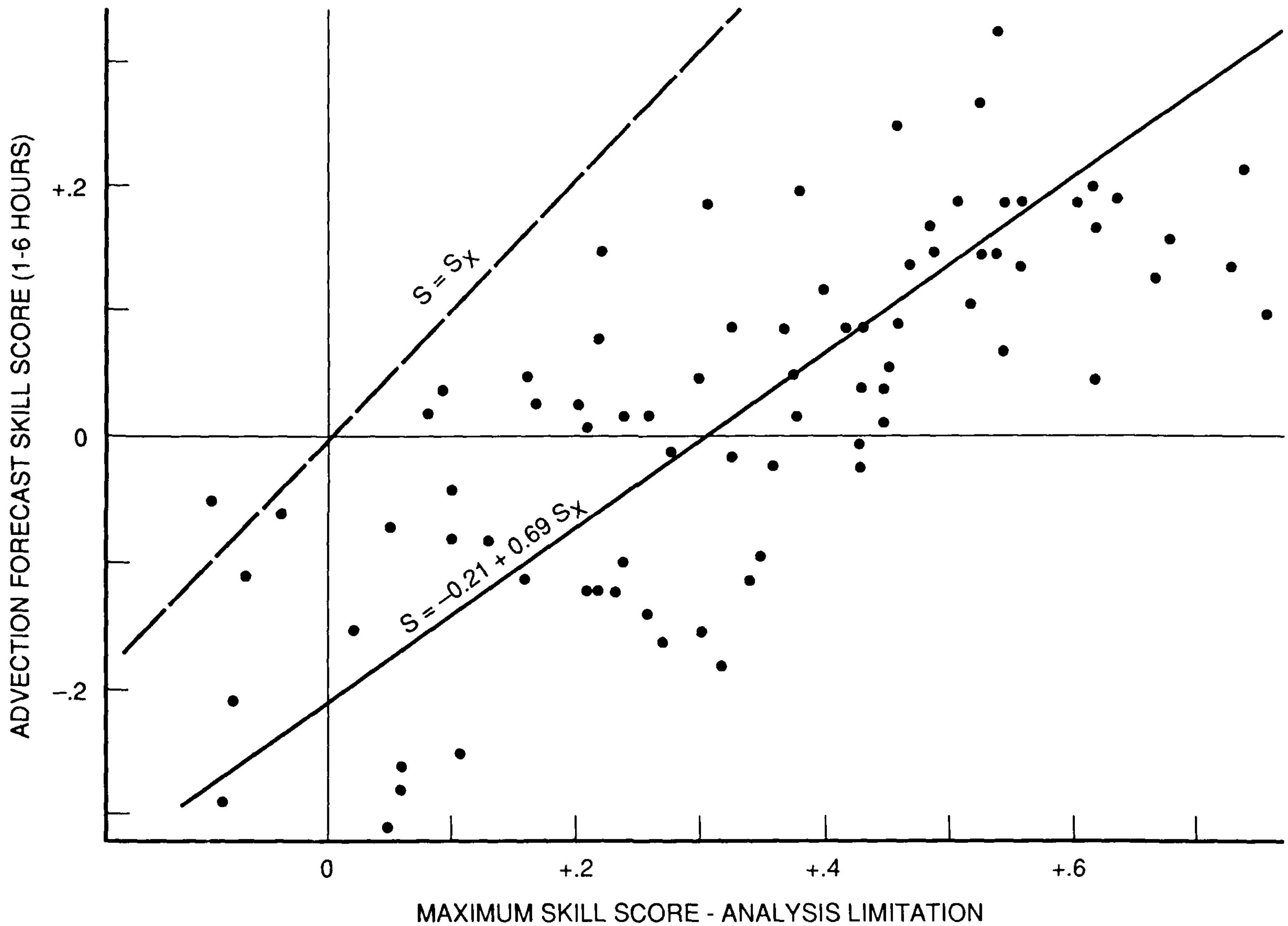

Figure 11. Maximum Skill Score versus Forecast Skill Score

synoptic scale (and somewhat smaller) disturbances predicted by the coarser scale. Three dimensional, high resolution "cloud" models (for example, 1-km) usually require expensive super-computers for real-time operation. However, in many cases, 2-D or even 1-D models with very high vertical resolution may provide the forecasts needed. These models would likely run in real time on "work stations" or "super-minicomputers" (now becoming relatively inexpensive and powerful), particularly if local terrain variations were not severe.

References

1. Muench, H.S. (1981) *Short-Range Forecasting of Cloudiness and Precipitation Through Extrapolation of GOES Imagery*, AFGL-TR-81-0218, AD A108678.
2. Muench, H.S. (1983) *Experiments in Ojective Weather Forecasting Using Upper Level Steering*, AFGL-TR-83-0328, AD A143393.
3. Fjortoft, R. (1952) On a Numerical Method of Integrating the Barotropic Vorticity Equation, *Tellus* **4**:179-194.
4. Muench, H.S. and Chisholm, D.A. (1985) *Aviation Weather Forecasts Based on Advection: Experiments Using Modified Initial Conditions and Improved Analyses*, AFGL-TR-85-0011, AD A160369.
5. NOAA/NWS (1980) The FOUS (FO12) Bulletin, NWS Technical Procedures Bulletin, Series No. 293.

Appendix A

The Extraction and Editing of Hourly Surface Weather Observations

As part of the AFGL McIDAS operating procedure, twice a week, two files containing the latest 100 hours of surface weather data for North America were dumped onto magnetic tape. These tape data were in the same packed form as on the disk, and normally would be read back into a "history" file and processed with McIDAS software. However, these archived data tapes also serve as a source for other projects such as these advection forecast experiments. The first step for outside use was to use a data extraction routine on a copy of the archive tape to scan through files for the 100-hr period that includes the particular case. Then, all stations within the area 30 to 50N and 65-95W were identified and 27 hours of data unpacked and placed on a case file.

Users of the McIDAS surface data base were aware that only a minimum amount of screening for errors or inconsistencies had been done by software, and large (though infrequent) errors occasionally resulted in unusual "bullseye" patterns in contoured fields. During the development of the advection forecast procedure[4], a procedure was set up for a computer data search for "spikes" in the time series of hourly reports. This procedure computes the 2nd derivative with respect to time, and compares the absolute value to a threshold for that parameter. For the parameter Q with data for the times $t-1$, t, and $t+1$, and the error threshold E_T, the test is:

$$| Q_{t-1} + Q_{t+1} - 2Q_t | \geq E_T \ .$$

In the first use of this procedure, only vector wind, temperature, and dewpoint were checked (thresholds of 23 m/s, 20 C, and 20 C, respectively), and when a value failed the test, all station data for a 5-hour period were displayed so that an interactive decision could be made to accept, replace or reject (set to "missing" value) the suspect data. Overall, about one observation in each 600 for any of the three

parameters was determined to be in error. In addition, there was a slightly smaller frequency of "false alarms" - large, rapid changes due to passage of fronts or convective disturbances.

In the March 84 data base experiments of this report, all parameters were checked, in a similar routine, with similar frequency of errors and false alarms. The error thresholds used are listed in Table A-1.

Table A-1. Error Threshold for Magnitude of 2nd Derivative for Hourly Weather Parameters

Parameter	Units	Threshold
Cloud Cover	(categories, 0 - 3)	5
Ln Ceiling Ht.		4.6
Ln Visibility		4.6
Ln Rainfall Rate		4.6
Temperature	(Celsius)	13
Dewpoint	(Celsius)	13
Vector Wind	(knots)	35

Appendix B

Processing NWS Model-Output-Statistics (MOS) Data Tape

The MOS data tape supplied to us by the USAF Staff Meteorologist at NWS Technique Development Laboratory used a format and order different from that found in the "FOUS" messages[5] of the FAA 604 data line, familiar to most forecasters. While this new format meant writing a special routine to extract appropriate data for each case, there was a benefit in that the predictions had higher resolution than in the FOUS format (note resolutions shown in Table B-1). For some parameters (such as temperature) a simple forecast data extraction was needed but for the probability forecasts (clouds, visibility, ceiling and precipitation) it was necessary to convert the category probability forecasts to parameter values to compare the MOS forecasts directly to those of advection and persistence. In this conversion, cumulative probabilities of exceeding each threshold were computed, then normalized so that the highest probability was 100 percent. A parameter value for the 50 percent probability was computed (based on natural logarithms of thresholds for ceiling and visibility) using linear interpolation. Before the MOS forecasts were verified, linear, temporal interpolations were made for those parameters with forecasts at six-hour intervals (see Table B-1), so that there would be forecasts of all parameters at 3-hour intervals. The primary verification of the MOS precipitation forecast (a probability of at least 0.01 inch of precipitation in a 6-hour period)was made by simply converting to a yes/no forecast using 50 percent as the threshold. Whereas the advection forecasts of yes/no were verified by one-hour precipitation measurements, the MOS forecasts were verified by six-hour measurements.

Table B-1. Characteristics of Forecast Parameters in MOS Data Base

Parameter	Resolution	Interval	First Forecast*
Temperature	0.001 Deg F	3-hr	1800 UT
Dewpoint	0.001 Deg F	3-hr	1800 UT
U-Component	0.001 kts	6-hr	1800 UT
V-Component	0.001 kts	6-hr	1800 UT
Ceiling Ht	0.1% (6 categories)	6-hr	1800 UT
Visibility	0.1% (6 categories)	6-hr	1800 UT
Cloud Cover	0.1% (4 categories)	6-hr	1800 UT
Precipitation	0.1% (.01 in/6-hr)	6-hr	1800-0000 UT

* Forecasts made using 1200 UT LFM products and 1400 UT station data. Subtract 12 hours for the 0000 UT MOS forecast set.

Appendix C

Processing GOES Satellite Imagery Files from McIDAS

The GOES imagery data archived on tape by McIDAS requires considerable processing before a suitable form of the data can be used in the advection forecast routines. The imagery files contain values representing brightness in visible and IR channels as seen from a geostationary platform, arranged in an array based on satellite sensing coordinates. These visible and IR values have been related to cloud cover, rainfall rate and reflectivity.[C-1] To forecast these parameters, the approach used in this study was to obtain the visible and IR brightness values around each of the half-degree latitude-longitude gridpoints and use algorithms to compute cloud cover and rainfall rate (visible reflectivity was also computed, but not used).

Rather than transforming the location of each satellite pixel (672×500 array) from satellite coordinates to latitude-longitude coordinates, a precise tranformation was made only for a 6×6 subset. At each point in this subset, a table was constructed to adjust the visible channel data for the isotropic and anisotropic scattering following a procedure developed by Muench and Keegan.[6] The tables were then used to adjust all visible image data in the area around each point. At the inner points of the 6×6 subset, 9-term biquadratic polynomials were constructed to express satellite row (I) and element (J) as functions of latitude (y) and longitude (x) ($I = a + bx + cy + dxy ...... + ix\ y$). These polynomials were used to find row and element numbers at each of the half-degree latitude-longitude analysis gridpoints. For

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C-1. Muench, H.S. and Keegan, T.J. (1979) *Development of Techniques to Specify Cloudiness and Rainfall Rate Using GOES Imagery Data*, AFGL-TR-79-0255, AD A084757.

each gridpoint an array of 10×12 adjusted visible satellite data (4-km resolution) were used to compute a mean reflectivity and a total cloud cover, based on a count of individual reflectivities greater than 24 percent. While the cloud cover values were quite reasonable for low and middle clouds, there was an underestimate of high clouds. In retrospect, a test for high clouds, using IR values, should be used in conjunction with visible channel data.

An algorithm[6] was used to estimate rainfall rate at each of the analysis gridpoints. This algorithm uses both visible and IR data, and since the latter has only 8-km resolution from GOES, rainfall rates were computed for a 5×6 array around each analysis gridpoint (rather than 10×12 used for cloud cover). The gridpoint rainfall rate was then the 30-point average.

Appendix D

Objective Analysis Procedure

The advection forecast routine requires that one determine both the location of the upstream point and the value of the forecast parameter at that point, even if the point lies between weather observing stations. One approach is to manually "analyze" the upper level flow pattern (streamlines and isotachs) as well as the surface weather pattern (contours or isopleths) and manually extract the necessary information. An alternative procedure is to use objective analyses to determine weather parameters over a network of uniformly distributed gridpoints and mathematically determine the necessary values at locations between gridpoints through interpolation. The application of the "Barnes" type of objective analysis to surface weather parameters was developed for a prior advection forecast study.[4] In this procedure, the grid point values are obtained through a series of successive corrections, starting with an initial "guess" (for example, an average of all station data, or an earlier analysis). At each stage, the gridpoint data are used to interpolate to a station value, the difference (or error) from the station value computed, and a weighted correction computed for surrounding gridpoints, with the weighting based on the distance between station and gridpoint as well as a "convergence factor" (parameter dependent). After all station observations have been processed, at each grid point the total weighted correction is divided by the total weighting, and the mean correction added to the previous analysis. Three such iterations were found to produce satisfactory analyses.

When the Barnes objective analysis technique was first used in making advection forecasts, a bilinear interpolation was used. If the values of the weather parameter at the four nearest gridpoints to a station are: Q_{00}, Q_{01}, Q_{10} and Q_{11} (left to right, top to bottom) and x and y are distance (in grid length units) from the station to the point 0, 0, then the interpolated value of Q at the station becomes:

$$Q = a_0 Q_{00} + a_1 Q_{01} + a_2 Q_{10} + a_3 Q_{11}$$

where $a_0 = 1 - x - y + xy$, $a_1 = x - xy$, $a_2 = y - xy$, $a_3 = xy$ (or, to avoid round-off problems, $a_0 = 1 - a_1 - a_2 - a_3$).

If the distance between gridpoints is small compared to the distance between stations, this bilinear interpolation should adequately describe the distribution of the field, at least for scales of disturbances down to the size limited by station spacing. However, some parameters, such as rainfall rate and visibility, have small scale disturbances and in some regions, such as metropolitan areas, station spacing is close compared to the grid spacing that can be conveniently handled. To avoid loss of information for these cases, one needs a nonlinear interpolation routine. As a step in this direction, a biquadratic interpolation was formulated. In this routine, x and y are the distance (in grid length units) from the station to the center point of a 9-point array (1,1). The interpolated value of Q becomes:

$$Q = a_0 Q_{00} + a_1 Q_{01} + a_2 Q_{02} + a_3 Q_{10} + a_4 Q_{11} + a_5 Q_{12} + a_6 Q_{20} + a_7 Q_{21} + a_8 Q_{22} \,,$$

where

$$a_0 = (y+1)(x-1)xy/4 \qquad a_5 = (x+1)(y-1)x/2$$

$$a_1 = (y+1)(x-1)y/2 \qquad a_6 = (y-1)(x-1)xy/4$$

$$a_2 = (y+1)(x+1)xy/4 \qquad a_7 = (y-1)(x-1)y/2$$

$$a_3 = (x-1)(y-1)x/2 \qquad x_8 = (y-1)(x+1)xy/4$$

$$a_4 = 1 - a_0 - a_1 - a_2 - a_3 - a_5 - a_6 - a_7 - a_8 \,.$$

In this biquadratic interpolation we must use 9 gridpoints instead of 4 and the multipliers are more complex forms of x and y. Without comprehensive testing, we cannot be certain that this interpolation produces better results than might be obtained by using a bilinear interpolation with half the grid spacing. (The computing times for both procedures would be roughly comparable.) However, from a physical point of view, fields must be expected to vary non-linearly between gridpoints and the biquadratic interpolation is at least a step in the right direction.

As mentioned previously, the Barnes technique uses a weighting function, and this can be expressed by:

$$W = \exp[-(x^2+y^2)/(36\gamma)]$$

where x and y represent the distance from the gridpoint to the station (in grid length units) and γ is a "convergence factor" dependent on the parameter. The values of γ used in this experiment are show in Table D-1.

In choosing these convergence factors, we should consider the scale size of important disturbances as well as accuracy and representativeness of the observations. Ideally, there should be an objective way to determine this factor. Lacking such a procedure, tests were made in which objective analyses were made to find the convergence factors that produced analyses best matching subjective hand-drawn analyses.[4]

Within the observational data are disturbances of all time scales greater than the limit imposed by the response time of the sensor (typically a few minutes). High frequency disturbances that cannot

Table D-1. Values of Convergence Factor (γ) for Analysis Parameters Used with Half-Degree Latitide-Longitude Grid

Parameter	Pass 1	Pass 2	Pass 3
U, V at 850-, 700-, 500-mb	0.4	0.1	0.02
Cloud Cover	0.4	0.1	0.02
Ln Ceiling Height	0.4	0.1	0.02
Ln Visibility	0.4	0.1	0.02
Ln Rainfall Rate	0.4	0.1	0.02
Temperature	0.3	0.06	0.012
Dew Point	0.3	0.06	0.012
U-Component (surface)	0.3	0.06	0.012
V-Component (surface)	0.3	0.06	0.012

be adequately resolved by hourly observations pose a potential problem, as attempts to forecast these disturbances by advection or change-advection will likely lead to increased error. To reduce effects of high frequency disturbances, a RTM was computed and used in the objective analyses. The RTM can be described by:

$$Q_t = (1-s)\ Q_{t-1} + s\ Q_t$$

where s Q_t is the smoothed value, Q_t the original observation and s the smoothing factor. Values of s used in the forecast experiment are shown in Table D-2.

Table D-2. Values of Smoothing Factor(s) Used to Compute Running-Time-Mean

Parameter	s	Parameter	s
Cloud Cover	0.7	Temperature	0.8
Ln Ceiling Ht	0.6	Dew Point	0.8
Ln Visibility	0.6	U-comp. Wind	0.5
Ln Rainfall Rate	0.6	V-comp. Wind	0.5

For weather systems moving about 25 kt (10 - 15m/s) and a half-degree latitude-longitude grid analysis, the ideal filter would remove disturbances less than 100 nm (180 km) size and shorter than a 4-hour period. The RTM is a simple filter to use and partially achieves this goal, but it does dampen 4- to 12-hour periods more than desired. No doubt other filters could be used that would be better suited to the task. In addition, a simple space filter should also be applied at least to the last stage of the objective analyses.